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Learning adaptation to climate change from past climate extremes:

Evidence from recent climate extremes in Haryana, India

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Abstract

Purpose – Conservation agriculture-based wheat production system (CAW) can serve as an *ex ante* measure to minimize loss due to climate risks, especially the extreme rainfall during the wheat production season in India. This study aims to examine whether farmers learn from their past experiences of exposure to climate extremes and use the knowledge to better adapt to future climate extremes.

Design/methodology/approach – The authors used data collected from 184 farmers from Haryana over three consecutive wheat seasons from 2013-2014 to 2015-2016 and multivariate logit model to analyse the driver of the adoption of CAW as an *ex ante* climate risk mitigating strategies based on their learning and censored Tobit model to analyse the intensity of adoption of CAW as an *ex ante* climate risk mitigation strategy. Farmer's knowledge and key barriers to the adoption of CAW were determined through focus group discussions.

Findings – The analysis shows that the majority of farmers who had applied CAW in the year 2014-2015 (a year with untimely excess rainfall during the wheat season) have continued to practice CAW and have increased the proportion of land area allocated to it. Many farmers shifted from CTW to CAW in 2015-2016.

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Practical implications – While farmers now consider CAW as an *ex ante* measure to climate risks, a technology knowledge gap exists, which limits its adoption. Therefore, designing appropriate methods to communicate scientific evidence is crucial.

Originality/value – This paper uses three years panel data from 184 farm households in Haryana, India, together with focus groups discussions with farmers and interviews with key informants to assess if farmers learn adaptation to climate change from past climate extremes.

Keywords Climate change adaptation, Conservation agriculture, *Ex* ante risk coping strategy, Learning from past climate extremes, Turbo happy seeder

Paper type Research paper

1. Introduction

Wheat (*Triticum aestivum* L.) is the most important cereal crop in India and is grown in about 29 million ha (Majumdar *et al.*, 2013). It is a staple food, supplying about 61 per cent of India's protein requirement (Sapkota *et al.*, 2014) and its assured supply is essential for national food and nutrition security. Analysis of trends in wheat production shows that yields have stagnated, as the beginning of the twenty-first-century with various possible causes including climate change and climate variability (Saharawat *et al.*, 2010; Majumdar *et al.*, 2013; Jat *et al.*, 2016). Therefore, to cope with increasing climate risk, wheat production systems need to be more robust and resilient to buffer the effects of extreme climate events (Jat *et al.*, 2014; Sapkota *et al.*, 2015; Jat *et al.*, 2016; Aryal *et al.*, 2018a; Sapkota *et al.*, 2018; Aryal *et al.*, 2019).

Conservation agriculture-based wheat production system (CAW), based on the principle of minimum soil disturbance, continuous ground cover and appropriate crop rotation, provides an alternative to the conventional system to enhance the resilience of agriculture to climate variability through better adaptation to climate change (Aryal *et al.*, 2016), reduce GHG emissions (Aryal *et al.*, 2015; Sapkota *et al.*, 2015; Kakraliya *et al.*, 2018) and reduced air pollution through the elimination of residue burning (NAAS, 2017; Tallis *et al.*, 2017). A recent study (Aryal *et al.*, 2016) in Haryana, India showed that CAW better copes with climatic extremes than the conventional tillage-based wheat production system (CTW). The study found that wheat yield during the bad year (defined in terms of untimely excess rainfall during grain development) was 4.89 Mg ha^{-1} under CAW while it was only 4.23 Mg ha^{-1} under CTW.

As the knowledge gained from past experience to extreme climate events are critical to design and implement climate risk adaptation plans (Parry *et al.*, 2007; Wise *et al.*, 2014), one crucial question is whether farmers in Haryana adapted their wheat production system and adopted CAW based on their experience of climate extreme events during 2015 wheat season. This is because learnings derived from their own experience (i.e. learning by doing) and from neighboring farmers (i.e. noticing/communicating/social networks) is one of the important determinants of technology adoption (Cameron, 1999; Bandiera and Rasul, 2006; Crane-Droesch, 2018). Empirical research confirms that farm households learn from the choices made by other farmers and do the same (Besley and Case, 1994; Foster and Rosenzweig, 1995; Munshi, 2004). Therefore, it is important to understand whether farmers who experienced that CAW performed better under climate extremes during the 2015 wheat season, learned from their experience and increased the land area dedicated to CAW the following year. Although a technically viable *ex ante* climate risks reduction and coping strategy in agriculture, the use of CAW instead of CTW by farmers for this purpose is unknown. Understanding whether farmers gradually learn from past climate extreme events and adopt *ex ante* risk reduction measures provides with vital insights into farmer behaviour in relation to climate change adaptation.

Another important issue is that unlike other new technologies, CAW has economic benefits and a shorter gestation period (i.e. the time gap between initial investment and return). This is because the machinery needed for CAW [i.e. Turbo happy seeder (THS)] is readily available on rent and does not require large up-front investment.

Against this background, using three years panel data from 184 farm households in Haryana, India, together with focus groups discussions with farmers and interviews with key informants, this study seeks to address the following questions:

- Do farmers learn from past experience (for farmers who continued CAW adoption over a period of three years) and from their neighbors (for those who were non-adopters until 2014-2015 wheat season and adopted in 2015-2016 after observing that their neighbors benefited by CAW in both bad and normal year)?
- If not, why are farmers cautious about expanding the area under CAW even though it copes better with untimely excess rainfall and has a higher economic benefit compared to CTW? and
- What are the potential implications for future design of climate change adaptation in agriculture? This paper presents an empirical analysis of climate-adaptive decision-making by farm households using real-world situations.

2. Extreme climate events in wheat season, loss of crop yield and public burden

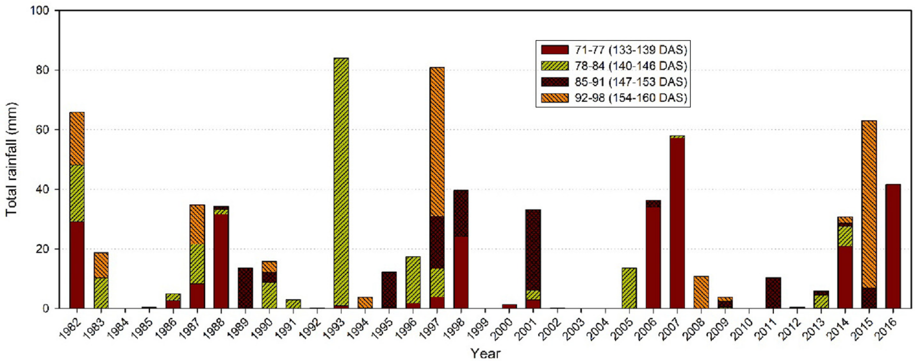
Climatic variability, especially rainfall variability (i.e. both drought and excess rainfall) and end-of-season high temperatures severely impact wheat production in India. Many studies have demonstrated negative effects of high temperature during wheat maturity period, i.e. "terminal heat" in India (Jat *et al.*, 2009; Lobell *et al.*, 2012; Tashiro and Wardlaw, 1989; Samra and Singh, 2004; Gupta *et al.*, 2010).

Early planting can help wheat escape terminal heat but increases the probability of loss due to high rainfall during the harvesting stage. Winter rains are largely unpredictable and rainfall immediately after irrigation is the most detrimental as it results in prolonged waterlogging leading to a yellowing of leaves and stunted growth of wheat. Waterlogging during the grain-filling stage also causes blackening of the wheat ear-head and loss of grain fill (Aryal *et al.*, 2016). Even if grain filling occurs, it will lead to substantial yield loss due to shriveled and light-weighted grains. Rainfall during maturity can increase the moisture content of the grains, making them unsuitable to sell directly from the field. Analysis of long-term rainfall data (1982-2016) from the study sites reveals that critical stage of wheat maturity received intensive rainfall in 10 out of 34 years (Figure 1).

Conservation agriculture (CA) has been advocated as one of the solutions to address higher temperature stress in wheat production by advancing wheat planting dates, by conserving soil moisture through reduced run-off and evaporative losses and by changing the thermal properties of the soil surface (Sapkota *et al.*, 2015). CA not only conserves moisture during drought conditions but also enhances infiltration and percolation of water in the event of excess rainfall. Retention of residue in CA also controls soil erosion, which otherwise would occur in the event of an intense downpour.

3. Study area and data

In this study, authors used the panel data collected from 184 wheat farmers of Karnal district, Haryana for three consecutive wheat seasons of 2013-2014, 2014-2015 and 2015-



Notes: Within the wheat maturity period (on average, 133-160 days after sowing, i.e., 71-98 Julian days), each stack shows the intensity of rainfall within a week. Rainfall of more than 20 mm in a week during this period is considered undesirable (bad) in terms of excess rainfall

Figure 1. Distribution of weekly rainfall during the wheat maturity period from 1982-2016 in the study area

2016. Data were collected from 10 village clusters (scattered over 15 villages) of Karnal district.

In the survey of 2014-2015, a total of 208 (50 per cent each from CAW adopter and no-adopter) farmers were surveyed. Same farmers were also surveyed in the 2015-2016 season. However, as 24 farmers had changed location, the sample size for the current study was reduced from 208 to 184. The data encompasses the information on major household characteristics, market and location characteristics, areas under CAW and CTW, production inputs, crop management, and grain yield under these two alternative wheat production systems. Authors have data for three consecutive years.

Haryana is selected as the study area for the following reasons. Firstly, it suffered from untimely excess rainfall in the year 2014-2015 during the wheat production season, which damaged the wheat crop over 0.5 million ha in the state (Government of Haryana, 2015). As a compensation to the farmers suffering from crop loss, Haryana Government spent about Rs. 11bn[1] (i.e. US$174.72mn) in 2015 (Government of Haryana, 2015). Therefore, any alternative wheat production system that reduces the wheat crop damage due to such climatic risks can significantly reduce the farmers' loss and also the economic burden of the government. Secondly, in Haryana, many farmers follow CAW and in the focus group discussion (FGD) in 2014-2015 (Aryal *et al.*, 2016), farmers reported that CAW suffered less from untimely excess rainfall as compared with CTW. Thirdly and most importantly, a study in Haryana by Aryal *et al.* (2016) compared wheat yield in both bad and good years and concluded that CAW performed better than CTW in both years. Therefore, it is important to understand if this knowledge was well communicated among the farmers and if farmers considered CAW as an *ex ante* adaptation measure to extreme rainfall during the wheat production season in Haryana.

4. Analytical framework and estimation issues

This study uses both quantitative and qualitative methods for the analyses of the data and in-depth understanding of CAW adoption from learning. Using mixed methods – econometrics methods to rigorously analyse the CAW learning data and FGD to probe deeper to understand farmers' views and experience about CAW managed to bring forth issues, which otherwise would be overlooked. The main focus was whether farmers learn from past experiences, and also from their social networks (Bandiera and Rasul, 2006; Hanna *et al.*, 2014; Crane-Droesch, 2018) and the importance of learning in the adoption process (Cameron, 1999).

4.1 Quantitative methods

This study applies two robust econometric methods for quantitative analysis. It used a multinomial logit model to analyse the farmers' adoption of CAW as an *ex ante* climate risk mitigating strategies based on their learning and a censored Tobit model to analyse the driver of the intensity of adoption of CAW as an *ex ante* climate risk mitigation strategy. (For details on multinomial logit and censored Tobit models, see Greene, 2003 and Wooldridge, 2010).

4.2 Qualitative methods

This study uses micro-interlocutor analysis (MIA) for analysing information obtained from FGD organized in Shambli village of Karnal district (Haryana). In MIA, information from the FGD is analysed by delineating participants who respond to each question, the order of responses and the nature of responses (e.g. focussed and unfocussed) and also the nonverbal communication used by each of the FGD participants (Sovacool *et al.*, 2017; Onwuegbuzie *et al.*, 2009). Using this method, the current study better conceptualizes the role of conversation analysis in analysing data collected from FGD.

The FGD concentrated on the two types of questions, i.e. general questions related to farmers knowledge and perception on climate change in agriculture, and more focussed questions on CAW and its adoption as an *ex ante* risk coping measure. The general questions on farmers' knowledge and perception are as follows:

- Is climate change a major problem in agriculture?
- Do you believe that some agricultural interventions can reduce the impacts of climate change on agriculture?

The questions on CAW and its adoption as an *ex ante* climate risk coping measure are:

- Do farmers know that some practices help adapt to climate extremes, and thus, can be used as an *ex ante* climate risk coping strategies?
- Does CAW better cope with extreme rainfall during the wheat harvesting period?
- Is CAW cost-effective and more productive compared to CTW?
- Have you used CAW? What are the major reasons for adoption or non-adoption of CAW?

Through FGD targeted at CAW, authors managed to gather extremely useful information from the participants, which are usually missed by pure quantitative methods.

5. Results and analysis

5.1 Descriptive statistics

5.1.1 Description of the variable used in the study. Table I presents the summary statistics of the variables used in the study. The average age of household heads is 41 years for both adopters and non-adopters of CAW, which indicates that most of the farmers were middle years of age. Result also shows that a large majority of the household (approximately 95 per cent) were literate and further segregation of the education level of the household head shows that 44 per cent of the household head had completed higher secondary level of education (i.e. Grade 12) and 25 per cent had completed secondary level (Grade 10), and 28

Variables	Mean	SD	Minimum	Maximum
Household characteristics				
Age of HH head (in yr.)	41.15	10.41	18	68
Young farmer dummy (i.e., HH head < 35 years)	28.37	45.18	0	1
Human capital				
Literate HH head				
Education of HH head	94.62	36.17	0	1
Primary education (base category: illiterate)	27.72	–	–	–
Secondary education (base category: illiterate)	24.46	–	–	–
Higher secondary and above (base category: illiterate)	43.48	–	–	–
Farm assets				
Land owned (ha)[a]	6.56	7.33	0.8	48
Own tractor	76.28	38.47	0	1
Own ZT drill machine	14.45	35.25	0	1
Social capital and training	–	–	–	–
Membership in cooperatives/institutions (Yes = 1)	36.45	47.24	0	1
Training (CA/soil and water management) (Yes = 1)	15.71	39.15	0	1
Constraints				
Use of weather information (Yes = 1)	52.43	50.07	0	1
Lack credit for agriculture (Yes = 1)	13.94	34.71	0	1
Lack of knowledge on CAW (Yes = 1)	65.49	41.32	0	1
Lack THS machine (Yes = 1)	72.11	44.59	0	1
Perception to climate change	–	–	–	–
Perceive CAW copes with climate extreme (Yes = 1)	59.12	41.54	0	1
Accessibility				
Distance to market (in Km)	4.86	3.29	1	18
Distance to extension service centre (in Km)	6.68	2.93	1	20
Distance to agricultural cooperatives (in Km)	2.06	1.49	0	10
Distance to nearest ZT service providers (in Km)	4.38	4.33	0	22
Number of Sample households (by village)				
Anjanthali/Balu	28	–	–	–
Badarpur/Dabkolikala	24	–	–	–
Bastada/Kutail	14	–	–	–
Chorpura	20	–	–	–
Daha/Uncha Saman	18	–	–	–
Gangar	20	–	–	–
Padhana/Sandhir	24	–	–	–
Pujam	20	–	–	–
Shambli	20	–	–	–
Taraori	20	–	–	–

Notes: [a]Values in the table refer to percentages unless stated; and of the total sample households, only 21 households have more than 10 ha of land. If we omit those households, the average land ownership is 3.83 ha with a standard deviation of 2.66 ha. Only seven households have more than 20 ha of land; THS = Turbo Happy Seeder

Table I. Summary statistics of variables used in the analyses

per cent had completed primary level of schooling. The education level of the household head plays a critical role in the adoption of technology as it increases the level of awareness and has implication of adopting agricultural technology.

The average land holding size of the sampled households was 6.56 ha; the adopter farm household had 6.6 ha compared to only 4.8 ha for non-adopters of CAW. The majority of the sample households owned tractors (approximately 76 per cent), which indicates that a significant proportion of the sampled households have pursued some form of farm mechanization. In the study area, about 14 per cent of the farm households owned zero-till (ZT) drill machine. Among CAW adopters, only five have their own THS, capable of seeding over previous crop residues. Therefore, most of the farmer rent machines required for CAW. Membership in cooperatives is essential for knowledge sharing and also for working together with a common interest and the results show that only 36 per cent of the sampled farm households affiliated with cooperatives, suggesting that it is crucial to increase membership in cooperatives. About 15.7 per cent of the farm household had received training on CA management, and of the total adopters, approximately 30 per cent of households have taken some kind of training in CA. Use of weather information is vital for farm households, but the data shows that in the study area only 52 per cent of the households used the weather data. The analysis also shows that about 14 per cent of the households did not have access to agricultural credit, 66 per cent lacked knowledge of CAW, and 72 per cent lacked access to THS machines. In total, 59 per cent of the total sample households perceive that CAW helps in coping with climate extreme whilst the analysis on the accessibility shows that the area under study is well connected; the average distance to the market, extension service, agricultural cooperatives and ZT service provider 4.86, 6.68, 2.06 and 4.38 km.

5.1.2 Wheat yield under conservation agriculture-based wheat production system and conventional tillage-based wheat production system. Table II provides information on the yield difference between CAW and CTW over three seasons. It is noteworthy that the wheat yield is significantly higher under CAW as compared to CTW in both normal and bad years. Wheat yield under CAW was higher by 0.41 Mg ha^{-1} in 2013-2014 (normal year), 0.66 Mg ha^{-1} in 2014-2015 (bad year) and 0.33 Mg ha^{-1} in 2015-2016 (normal year) all significant at 1 per cent level of significance. The result also shows that the yield is higher and significant at 1 per cent in normal compared to the bad year for both CAW and CTW practicing farm households; however, the difference in the wheat yield between normal and bad years is higher for CTW compared with CAW, which indicates the compared to CTW, CAW does better in reducing the yield shock in the bad year. This is consistent with the findings of Aryal *et al.* (2016), and thus, provides a strong basis to examine why farmers are not shifting from CTW to CAW. The shifting from CTW to CAW is the consequence of the out-performance of CAW over CTW in terms of wheat yields over considered years.

5.1.3 Trend of land operated and allocated to conservation agriculture-based wheat production system. The share of total operated land allocated to CAW has substantially increased over a period of three years (Table III), indicating that many farmers have learned from their own experience and neighbors experience and have adopted CAW as an *ex ante* climate risk coping measure. Most importantly, a sharp increase in the percentage of the total operated land allocated to CAW among its adopters was observed in the year 2015-2016 compared to the year 2014-2015. The average proportion of land allocated to CAW was 19.84 per cent in 2013-2014, 28.93 per cent in 2014-2015 and it was 69.29 per cent in 2015-2016. From this analysis, it can be inferred that CAW was increasingly recognized as an important practice to minimize the loss due to climate risk.

5.1.4 Summary of farmer learning from past experience of climate extremes during the wheat season. Understanding whether farmers learn from past experiences (here, from past climate extreme event, which occurred during the 2014-2015 wheat season in the study area) and how they learn has important implications in designing policies to scale out the farming technologies (Cameron, 1999). Table III presents the distribution of farmers by their learning status. Approximately, 34 per cent of the farm households did not learn from the past

Table II. Wheat yield (Mg ha^{1}) under alternative production systems

Wheat production system	Average wheat yield (Mg ha^{-1}) 2013-2014: normal year (A)	2014-2015: bad year (B)	2015-2016: normal year (C)	Yield difference A-B	Yield difference C-B	*t*-test A-B	*t*-test C-B
CAW	5.46 (0.052)	4.89 (0.056)	5.13 (0.031)	0.57[a]	0.24[e]	7.55***	4.71***
CTW	5.05 (0.58)	4.23 (0.066)	4.82 (0.028)	0.82[b]	0.59[f]	9.38***	5.17***
Yield difference between CAW and CTW (Mg ha^{-1})	0.41[c]	0.66[d]	0.31[g]	–	–	–	–
t-test	5.19***	7.59***	7.34***	–	–	–	–

Notes: ***Refers to significant at 99 per cent confidence level; observations are combined observations; standard errors are reported in parentheses. CAW and CTW refer to conservation agriculture-based wheat and conventional tillage-based wheat, respectively; [a]Yield loss due to climatic risk (untimely rain at the ready to harvest stage of wheat crop) in CAW between year 2013-2014 and year 2014-2015; [b]Yield loss due to climatic risk (untimely rain at the ready to harvest stage of wheat crop) in CTW between year 2013-2014 and year 2014-2015; [c]Yield gap between CAW and CTW in a normal year, i.e., in year 2013-2014; [d]Yield gap between CAW and CTW in bad year (here, year with untimely rain at the ready to harvest stage of wheat crop), i.e., year 2014-2015 – address climatic variability; [e]Yield gain because of the adoption of CAW in year 2015-2016 (normal year) compared to year 2014-2015 (Bad year); [f]Yield difference between the good year 2015-2016 and bad year 2014-2015 under CTW; [g]Yield gap between CAW and CTW in normal year, i.e., in the year 2015-2016

Year	No. of households[a]	Share of land allocated to CAW (average)
Adoption of CA-based wheat production system (CAW) by year		
2013-2014	104	19.84
2014-2015	104	28.93
2015-2016	139	69.29
Learning from past experience of climate extreme		
Learning from past climate extremes	No. of farm households	–
No learning[b]	63	–
Learning from own experience[c]	77	–
Learning from neighboring farmers experiences[d]	44	–
Total	184	-

Notes: [a]Of the total sample of 208 households, 104 were the adopters of CAW in the years 2013-2014 and 2014-2015. In 2015-2016, 44 households who were non-adopters in the previous years started CAW, and hence, the number of CAW adopters increased to 139 households; [b]this includes farmers who have not adopted CAW in their land in both 2014-2015 and 2015-2016, and also farmers who have adopted CAW in 2014-2015 but have not increased the share of land under it in 2015-2016; [c]this includes farmers who applied CAW in their land in 2014-2015 and increased the share of land allocated to CAW in their total operated land in 2015-2016; [d]This includes farmers who did not apply CAW at all in their land in 2014-2015 but applied it in some or total land operated by them in 2015-2016

Table III. Learning from past experience on the adoption of CA-based wheat production system (CAW)

experience, 42 per cent learned from their own experience and 24 per cent learned from the neighbouring farmers experiences, which shows that the largest proportion (65 per cent) of the farmers learned about the climate extremes either from their own experience or the experience of the neighbouring farmers.

5.2 Econometrics analysis and result

5.2.1 Analysis of farmer learning from past experience to climate change adaptation in agriculture. Table IV (left panel) presents the results from the multinomial logit model on the factors influencing the learning from experience on climate change adaptation in agriculture among the farm households in the study area. The dependent variable is a categorical variable with three outcomes, i.e. no learning, learning from own experience, learning from neighboring farmers' experiences. As these outcomes are mutually exclusive, application of the multinomial logit model is one of the most preferred methods for econometric analysis. In the model, authors have used the outcome "no learning" as the base category, which means the findings are in comparison to those farm household heads who did not learn from past climate extreme events at all. The results show that age, education, training, and perception about technology matters for learning. Authors checked the robustness of the results with different specifications of the model- in the Model A authors used the age of the household head, and in Model B authors replaced the age of the household head with young farmer under 35 years, and authors also included the interaction term "young farmer and training".

The results show that the effect of age is negative and significant at 1 per cent level for learning from neighbours, indicating that the older farmers are less likely to learn about adaptation to climate change from neighbours. In the Model B, the result shows that the coefficient of the young farmer is positive and significant for both learnings from own experience and learning from neighbours, indicating that young farmers are more likely to learn about climate change adaptation. Education enables individuals to learn quickly. The

Table IV. Analysis of factors determining farmer learnings to adapt to climate change

Variables	Analysis of factors determining farmer learnings to adapt to climate change (marginal effects from multinomial logit model): base outcome (no learning) — Learning from own experience Model A	Learning from own experience Model B	Learning from neighbours Model A	Learning from neighbours Model B	Analysis of the intensity of learning from experience to adapt to climate change (Tobit model) — Specification A	Specification B	Specification C
Demographic							
Age of HH head	−0.038(0.026)	–	−0.045***(0.016)	–	−0.045**(0.021)	–	–
Young farmer dummy	–	0.096***(0.023)	–	0.116**(0.052)	–	0.126***(0.027)	–
Human and social capital							
Primary educationa	0.305(0.224)	0.278(0.214)	−0.105(0.225)	−0.115(0.205)	0.078(0.107)	0.079(0.109)	0.105(0.125)
Secondary educationa	0.115***(0.037)	0.105***(0.031)	0.095***(0.024)	0.094***(0.022)	0.095***(0.027)	0.097***(0.031)	0.083***(0.024)
Higher secondary and above[a]	0.035**(0.016)	0.031**(0.014)	0.043**(0.021)	0.041**(0.019)	0.045**(0.021)	0.041**(0.018)	0.041**(0.020)
Training	0.388***(0.131)	0.311***(0.126)	0.151(0.377)	0.151(0.374)	0.266***(0.072)	0.295**(0.121)	0.316***(0.107)
Lack knowledge	−0.437***(0.119)	−0.437***(0.119)	−0.132**(0.078)	−0.137***(0.076)	−0.311***(0.119)	−0.301***(0.119)	−0.332***(0.078)
Membership in cooperatives	0.256***(0.041)	0.210***(0.062)	0.326***(0.112)	0.265***(0.098)	0.097(0.109)	−0.019(0.125)	0.152(0.110)
Farm assets							
Land owned (ha)	0.291***(0.087)	0.263***(0.087)	0.288***(0.088)	0.267***(0.078)	0.014**(0.006)	0.024***(0.007)	0.017***(0.007)
Own tractor	0.545(0.779)	0.545(0.779)	−0.936(0.624)	−0.936(0.624)	0.011(0.127)	−0.021(0.140)	−0.021(0.122)
Access to facilities and infrastructure							
Distance to market	−0.021(0.094)	−0.021(0.094)	−0.077(0.110)	−0.077(0.110)	−0.017(0.017)	0.000(0.019)	−0.002(0.016)
Distance to extension centre	−0.131(0.112)	−0.127(0.102)	−0.116(0.096)	−0.099(0.106)	0.009(0.017)	−0.028(0.020)	0.011(0.017)
Lack credit	−0.348(0.427)	−0.378(0.429)	−0.224(0.814)	−0.234(0.802)	−0.422(0.547)	−0.573(0.627)	−0.049(0.563)
Distance to ZT service provider	−0.603***(0.231)	−0.617***(0.214)	−0.184***(0.054)	−0.181***(0.049)	−0.099***(0.035)	−0.106***(0.037)	−0.082**(0.034)
Perception of CAW on adaptation to climate change							
Perception on CAW	0.201***(0.044)	0.193***(0.039)	0.211***(0.054)	0.212***(0.054)	0.400***(0.108)	0.459**(0.192)	0.419**(0.131)
Interaction terms young farmer and training							
Young farmer*training[b]	–	0.263***(0.103)	–	0.171***(0.063)	–	–	0.191***(0.022)
Constant	5.905***(2.108)	5.835***(1.108)	4.873***(1.814)	4.894***(1.753)	−0.581(0.632)	0.272(0.627)	0.147(0.616)
Sigma constant	–	–	–	–	0.441***(0.037)	0.454***(0.042)	0.480***(0.039)
Pseudo R^2	–	–	–	–	0.317	0.323	0.341
Number of observations	184	184	184	184	184	184	184

Notes: [a]Base category is illiterate; [b]interaction term between young farmer and training; ***significant at 1 per cent; **significant at 5 per cent; *significant at 10 per cent, standard errors are reported in parentheses result shows that the household whose head has completed secondary and higher secondary and above are more likely to learn about climate change adaptation from their own experience and from neighbour in both Models A and B compared to a household headed by an illiterate farmer. The coefficient of the training dummy is positive and significant for learning from own experience in both Models A and B indicating that the household, which receives some kind of training in conservation agriculture has a higher probability of learning about climate change from their own experience. Lack of knowledge dummy is negatively associated with learning from experience and learning from neighbours in both Models A and B, which indicates the importance of information and knowledge in technology adoption. Similarly, other studies have also found that the lack of knowledge and insufficient information are causes of low adoption of CA by smallholder farmers in Southern Africa (Holden and Lunduka, 2014; Holden and Quiggin, 2017). The coefficient of the dummy membership in cooperatives is positive and significant at 1 per cent level of significance for learning from own experience and learning from the neighbour about climate change adaptation for both Models A and B.

The land area (ha) owned by the farm household is positive and significant (at 1 per cent level of significance) for learning from own experience and neighbour experience about climate change adaptation signifying that land holding of the household plays a critical role in learning about climate change adaptation. Land is the primary asset of the farm household, which influences their livelihood and income; therefore, those household with larger land assets are keen to learn and adopt any technology, which influences the farm productivity. Studies have shown that poor farmers tend to be risk-averse and that this constrains their uptake of new technologies (Dercon and Christiaensen, 2011; Karlan *et al.*, 2014). Though the tractor is also a key asset, it turned out to be insignificant in determining the learning outcome for the adoption of climate change adaptation.

All variables for access to facilities and infrastructure turned out to be insignificant except distance to ZT service provider. The distance to ZT service provider was negative and significant at 1 per cent level of significance for learning from own experience and learning from neighbours' experience for both Models A and B, signifying that farther the ZT service provider is, the less likely that the farmer will learn about climate change adaptation.

Perception of CAW is a critical determinant of farmers' learning about climate change adaptation. The results show that the farmers who perceive that CAW helps in combating climate change are most likely to learn both from their own experience and from the experience of their neighbour. The interaction between dummy young farmer and training is positive and highly significant, indicating that the young farmers who receive training are most likely to learn from their own experience and from the neighbour.

5.2.2 Analysis of intensity of learning from experience. In the current study, the intensity of learning is measured by the proportion of total operated land under CAW (i.e. land under CAW/total land). As many farmers have applied CAW on a part of their total operated land, the dependent variable ranging from 0 to 1 (0 if the farmer does not practice CAW and 1 if the farmer applied CAW on their entire operated land). For such data structure, standard censored Tobit model is used to assess the determinants of its intensity. The result of the pooled Tobit model is provided in Table IV (right panel). To test the robustness of the result, the authors estimated three Tobit models. In Model A, authors used the age of the household, and in Model B, authors replaced it with the young farmer and the interaction term (young farmer and training), and in Model C, authors used only the interaction of young farmer and training. The findings show that farmer's intensity of learning from experience to cope with climate change is negatively associated with age, i.e. older farmers are less likely to learn from experience. The coefficient of the young farmer in Model B is positive and significant at 1 per cent, which similarly indicates that young farmer are more likely to learn from the experience.

Education of the household head appears to influence the intensity of learning from experience. The coefficient of the secondary and higher secondary and above is positive and significant at 1 per cent, which means that intensity of learning is higher for those households with a secondary and higher secondary and above level of education compared to illiterate. As envisaged, the training on CA technology is also positive and significant at 1 per cent level of significance; therefore it can be concluded that training plays a vital role in influencing farmers to increase the intensity of learning about CA technology. Lack of knowledge turns out to be a major constraint in the intensity of learning about the climate change coping mechanism. The coefficient of the lack of knowledge is positive and significant at 1 per cent level of significance. The membership dummy is insignificant in influencing the intensity of learning.

As the land is a primary asset of the farmers, the study found that the landholding critically influences the farmer learning about the mechanism to cope with climate change. The result shows that the intensity of learning for farm household increases with the increase in the land asset. However, tractor ownership is not a significant driver of learning about climate change adaptations.

Amongst all factors related to access to facilities and infrastructures, only distance to ZT service centre turns out to be significant drivers of the intensity of learning about adaptation to climate change. The coefficient of the distance to ZT service centre is negative and significant at 1 per cent level of significance highlighting that the closer a household is to the ZT service provider the more probable that the intensity of learning increases. The perception of CAW is a critical determinant of the intensity of learning to cope with climate change. The farmers who perceive that CAW helps in coping with climate change are more likely to learn compared to those who do not believe that CAW helps in coping against climate change risk. The coefficient of the perception on CAW is positive and significant at 1 per cent level of significance in all three Models A, B and C. The interaction terms of young farmer and training is positive and significant at 1 per cent level of significance, highlighting that the intensity of learning is higher for young farmers who have received training on CA technology.

5.3 Results of the focus group discussion with farmers and key informants survey

About 57 per cent of the total participants in the FGD consider that CAW can better cope with extreme rainfall during the wheat season, and they consider the primary reason behind this is the better root system. However, they reported the need for better management of CAW as it requires proper timing of weed management. This is where the significant knowledge gap exists and the major reason why some of the participants do not agree with the agronomists working in their area.

Nearly 23 per cent of the participants are not convinced that CAW really serves as a climate risk mitigation measure and also doubt the economic benefits. They were of the opinion that several factors affect the yield and found it hard to believe that CAW alone was the reason behind the lower losses observed in a bad year, i.e. 2014-2015.

Farmers reported that the majority of the extension workers' recommendations are based on high-input intensive agriculture, and such practices are not suitable for CA-based systems. According to them, farmers/local cooperatives/local custom hiring service providers who work with external agricultural projects are more informative than the government extension service providers. As a result, farmer-to-farmer communication is the dominant method to transfer the knowledge on CAW, which suggests the need for better training of extension staff on CAW.

Young farmers are more enthusiastic about CAW and also about the mechanization of agriculture. However, they are worried about declining farm size, which may reduce the benefits of CAW. Authors also discussed why young farmers are more inclined towards CAW as compared to relatively older ones. Some old farmers replied that "today's youth are better than us in using modern communication technology, such as mobile apps and internet". They added that "young farmers can access new information easily, which is beyond our capacity. This is mainly because of increasing technological innovations over time".

Overall, there is a positive response to CAW. Nevertheless, there is a need for closer integration between agricultural scientists, farmers, and government and private extension service providers to reduce the knowledge gap on CAW and to improve local knowledge. The major problems highlighted by the farmers are as follows:

- *Farmers' knowledge gap*: CAW is knowledge-intensive and requires the operation of modern machinery. There is a regular improvement in available machines for zero tillage. For example, the original ZT drill machine could not seed wheat in the presence of rice straw on the field, but the THS can perform this task. Changing from one type of machine to another requires a flow of information. This also requires new knowledge to operate the machine together with its proper calibration. Farmers' also focussed on the need for a replacement facility for old ZT drill machines when a new improved version is available on the market. Almost 25 per cent of the participants were not convinced that CAW performed better than the conventional practice and insisted that the weed problem was challenging to address in CAW. This aspect of CAW warrants further research and development.
- *Narrow window for farmers and service providers for operating THS*: The time gap between paddy harvesting and planting of wheat in North-West India is 7-10 and 15-20 days in fields planted with basmati/scented and coarse rice, respectively. If farmers cannot access the THS on time for seeding, the field loses soil moisture resulting in low germination of wheat, eventually causing a yield penalty.
- *Machine service and technological backstopping*: At the time of wheat sowing, service providers are unable to meet the demand of every farmer as the numbers of custom hiring services are limited north-west India.
- *Small farmers*: Almost 70 per cent of the farmers are smallholder. They have no economic capacity to purchase the THS and mostly rely on custom hiring services. Most of the farmers have traditional machinery (normal multi-crop planter and ZT machine, and 35 horsepower (Hp) tractor) for wheat sowing. There is a need to replace these machineries with the new ones (THS and tractor with >50Hp as THS requires high-power tractor). Any further improvement in CAW machinery needs further investment from farmers to use the improved version, and it is not profitable to buy a new machine every time. Provision of better custom hiring services is the only option for marginal and small farmers as agriculture is no longer a profitable venture for them.
- *Attitude*: For several years, farmers have been using clean cultivation. As the field sown with THS looks untidy during the first 45 days of crop growth, many farmers do not like it and so can be reluctant to change; a change in mindset is therefore needed.

- *Weed management*: Existing combine harvesters used for harvesting rice are not equipped with a straw management system (SMS), and thus, it leaves behind the loose residue in a swath. Due to the unavailability of labour on time, the manual spreading of loose residues before using THS is delayed. Because of this, in few cases (depending on management history of the fields), weeds emerge before wheat seeding and are covered by the residues, thereby escaping the herbicides droplets/drifts. In such cases, application of herbicides may not match with the crop stage, and weed control becomes difficult.
- *Germination problem due to soil compaction caused by machinery*: Most of the farmers use the combine harvester for rice harvesting, and because of the heavy weight of the combine harvester, it causes soil compaction below the rear wheels, which farmers report cause poor germination and emergence of wheat. It is also not possible with the THS to seed wheat on an uneven soil surface. This requires better understanding and planning in the use of the combine harvester so that operations are timed for when soil moisture conditions are optimal.

6. Discussion and policy implications

The findings of this study have important policy implications. Given that the majority of farmers believe that CAW contributes to climate change adaptation, removing barriers to adoption can help enhance farmers' income with and without climatic extremes. Hence, identifying and strengthening existing institutions rather than creating new ones is required to enhance the adoption of CAW. Despite some barriers to adopt CAW, the knowledge on CAW is spreading among farmers, primarily through farmer-to-farmer communications and farmers meeting in the local farmer clubs. Based on the findings, the authors suggest the following to promote CAW:

- *Facilitate farmer-to-farmer communication*: Facilitating farmer-to-farmer communication are crucial components in improving farmers' knowledge on CAW and its uptake. These findings corroborate other findings (Aryal *et al.*, 2018c, 2018a, 2018b; Fisher *et al.*, 2018), which reported that farmer-to-farmer communication plays a major role in the adoption of climate-smart agricultural practices. Therefore, policy should focus on the importance of learning in technology diffusion and provide support to educational/training facilities related to CAW rather than merely focussing on input subsidy. Effective communication increases farmers' capacity to adapt to extreme climate events and minimizes the financial burden of the government in terms of compensatory payments, which could otherwise be used for nutrition/food security.
- *Improve custom hiring services of CAW machineries*: Insufficient custom hiring of THS is one of the major constraints to farmer adoption of CAW in the study area. Although the Government of India has introduced a scheme of about Rs. 11.5bn to incentivize *in situ* management of crop residues through subsidies that mainly target the THS and the SMS (Government of India, 2018), a broader policy to enhance the capacity to manufacture the required number of machines at the local level is essential. In 2014-2015, the number of THS was only 600, while about 5800 THS are required to cultivate 0.35 m ha of agricultural land in Haryana state alone (Lohan *et al.*, 2018).
- *Revise crop loss compensation policy*: In the climate extreme event of the 2014-2015 wheat season, the Government of Haryana compensated only those farmers whose

crop yield loss was more than 30 per cent. This acted as a disincentive for farmers using CAW as their losses were less than those using conventional practices. Therefore, the compensation policy should also consider wheat production practices and not just a measure of losses.

- *Private sector involvement*: Engaging the private sector and the business community is essential for the rapid expansion of this innovative technology. Local government bodies help create a favourable environment to actively engage multiple private actors including farmers, civil society members and businesses by creating governance networks and conducive policies (Mees, 2017; Sovacool *et al.*, 2017; Tallis *et al.*, 2017).

7. Conclusion and way forward

CAW, which has been adopted by the farmers primarily to reduce production costs, is now being adopted as a climate risk coping measure. The findings show that farmers learn climate change adaptation through their own experience and through the experiences of their neighbours. Several factors determine these learnings and their use for climate risk adaptation. Farmer learning and uptake of new technology is not only related to the characteristic of technology but also how well the technology fits the farming system and its impact on farmers' livelihood. Even though the technology has no investment risks, other factors related to the technology and farmers can largely influence its uptake.

Learning/communication was found to be the most crucial factor for CAW adoption. Therefore, providing support to agricultural education programmes for farmers rather than focussing solely on input subsidies and credit should be a major target for policy. A transformational change in agriculture is possible through better institutional support and improved service provision for CAW-based technologies. Climate change adaptation in agriculture, therefore, needs to focus on various other issues related to farm household and market characteristics, along with technology development. Designing an appropriate strategy to communicate scientific evidence to farmers, reshaping compensation policies and strengthening local extension institutions are essential.

At the local level, farmer-to-farmer communication was found to be a critical factor in promoting technology adoption (i.e. in the current study, learning from past experiences to cope with climate extremes). Targeting young farmers and training them to be lead farmers for new agricultural technology dissemination can substantially enhance CAW adoption.

Climate change adaptation in agriculture through technology adoption is a crucial topic and has multiple dimensions. Therefore, future research at multiple locations is necessary to address the issues further at a broader scale and to generalize its impacts in different states of India.

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Note

1. The exchange rate for the year 2015 is: Indian rupees (INR) 1 = US$0.016.

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